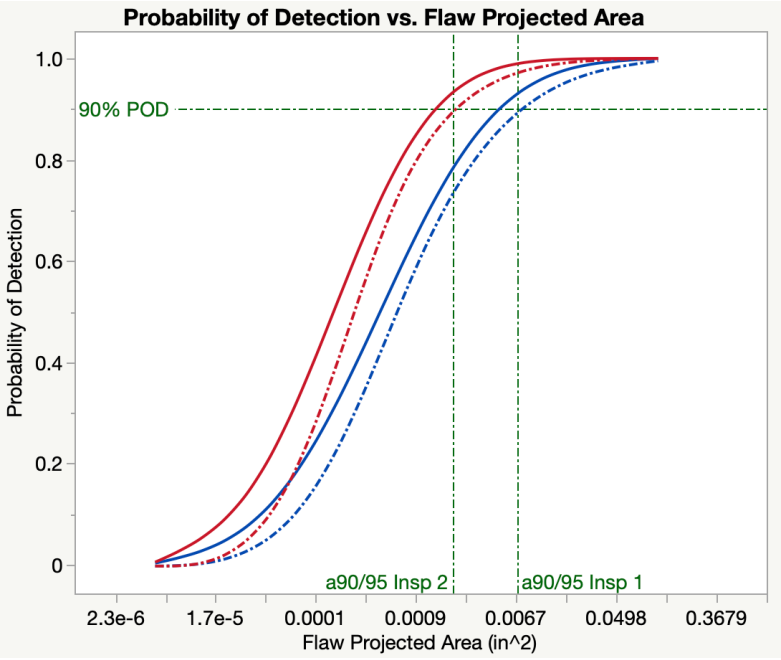
NASA NDE FRACTURE CRITICAL DETECTABLE FLAW SIZES HISTORY AND METHODOLOGY

Bill Prosser

June 27, 2023

Radiograph of Cracked Space Shuttle External Tank Stringer



P. Parker, A. Koshti, D. Forsyth, M. Suits,

J. Walker and W. Prosser

31st ICAF Symposium – Delft, 26-29 June 2023

Outline

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- History of NASA ”Standard” NDE Flaw Sizes
  - Flaw sizes provided in NASA Standard 5009
- New Methodology to Establish NASA Standard Flaw Sizes

Background

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- Minimum “reliably” detectable flaw size is starting point for fatigue and fracture damage tolerance analysis for fracture critical hardware
- NASA requirement (and others) is that NDE provide 90/95 Probability of Detection (POD)
- One (of many) factors that can affect NDE POD is inspector-inspector variability
- NASA addresses inspector variability by defining two types of NDE inspections for fracture critical applications
  - Standard NDE
  - Special NDE

NASA Special NDE

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- Anything other than Standard NDE
  - Different methods than those defined as Standard
  - Flaw sizes smaller than designated at Standard
  - Materials/geometries not “similar” to that tested for Standard
- **Individual inspector(s) to perform inspection must demonstrate 90/95 POD capability**
  - Costly to test inspectors to demonstrate capability
  - Inspectors must periodically be retested to ensure capability is maintained
- However, necessary in many situations when Standard NDE is not applicable

NASA Standard NDE

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- Conservative flaw sizes such that any qualified inspector "should" provide the 90/95 capability
  - **Individual inspector 90/95 POD demonstration not required**
  - 5 specific NDE methods (PT, MP, UT, RT, and ET)
  - Documented in Tables in NASA Standard 5009
- Standard NDE flaw sizes based (in part) on seminal NDE capability test program in early 1970's performed by Space Shuttle Program (Bishop Study)
  - Large number of flaws and multiple inspectors from multiple companies
  - Intent was to select flaw size such that 95% of inspectors provided 90/95 POD or better (i.e., 90/95/95 POD)

Two Step Approach Used to Estimate Standard NDE Flaw Sizes

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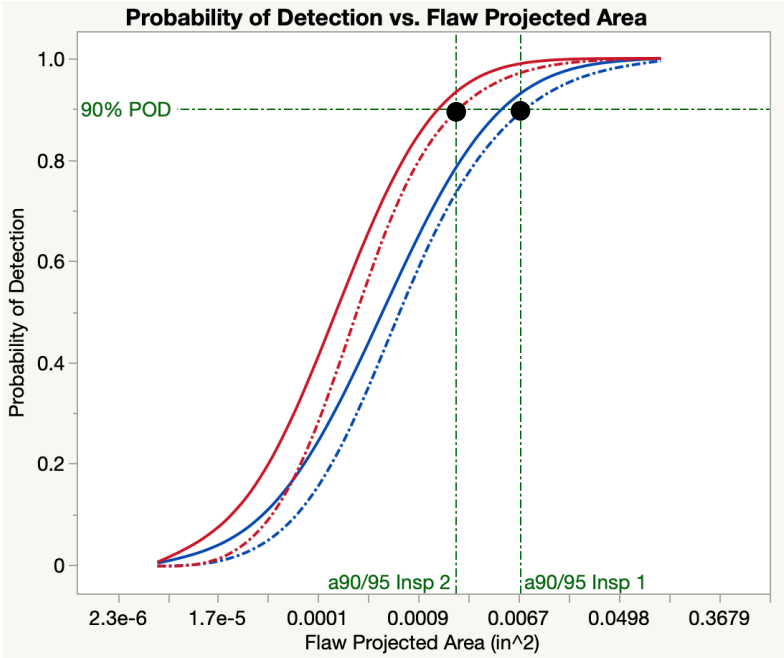
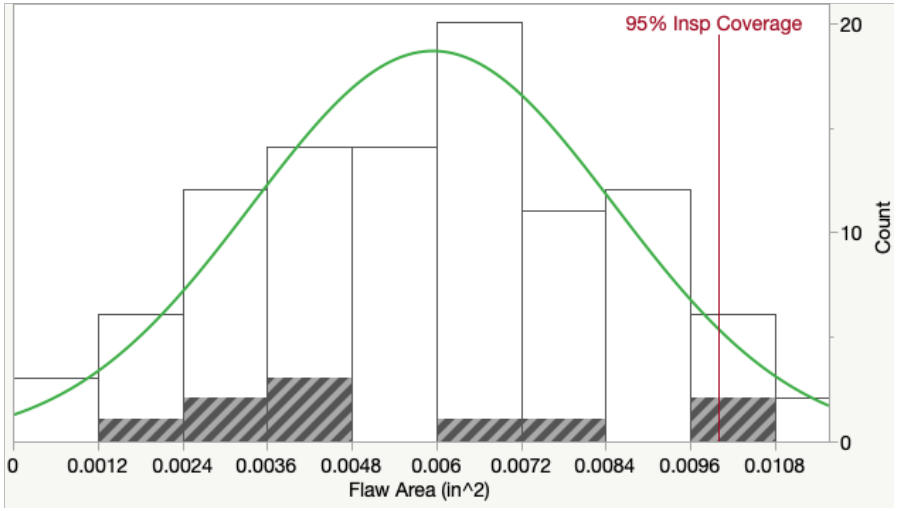
Multiple inspectors presented with the same set of flaws, and estimate determined for each inspector's detection capability.



Distribution of 90/95 flaw sizes estimated from which flaw size estimated such that 95% of inspectors provided 90/95 POD or better (a90/95/95)



Outlined histogram columns represent all 100 inspectors, and shaded columns are what we might get from a random sample of 10 of them

Motivation for Current Study

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- NASA Standard NDE flaw sizes used by NASA (and others) for over 50 years
- However, methodology to perform/analyze a Standard NDE demonstration never documented in NASA requirements
  - Needed to include new NDE methods (e.g., digital radiography) and reassess existing methods in light of technology improvements
  - Original methodology documented in test reports not consistent with more modern POD analysis methods (e.g., Mil-HDBK-1823)
- Initial intent was to develop “new” Standard NDE methodology, baseline against historical data to show consistency, and document in NASA requirements
  - Did not exactly go as planned!

- Multiple issues
  - Same flaw sets used for all NDE methods – led to inadequate flaw distributions to reliably estimate POD for some methods
  - Cracks etched even though etching only required for PT – may lead to nonconservative flaw estimates for methods like RT
  - Qualitative treatment of crack aspect ratio
  - Evolution of Standard flaw sizes to 5009 tables not well documented
    - Some flaw sizes based on qualitative engineering assessment or unreferenced additional POD studies
  - Study did not include blank specimens (i.e., without flaws) to estimate probability of false calls
  - **Sorted Group Ascent Method (SGAM) used for original study is nonconservative relative to modern (1823) POD analysis methods**

SGAM Issue and Impacts

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- "Groups" NDE results by flaw size and performs statistical analysis to determine POD of flaw size group
  - Inherent requirement is flaw sizes are constant within a group
  - Insufficient numbers of similar size flaws in original testing results in violation of assumption of constant flaw size in groups
- Results in estimated a90/95/95 flaw sizes being nonconservative for UT, EC, RT, and PT – inspector coverage more like 50% (i.e., average)
- For penetrant, miscalculated square root resulted in inspector coverage much closer to desired 95% - two wrongs make a right!

Reanalysis of Bishop Data

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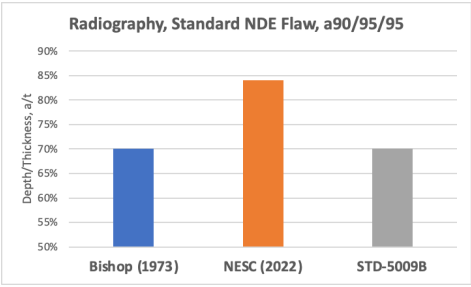
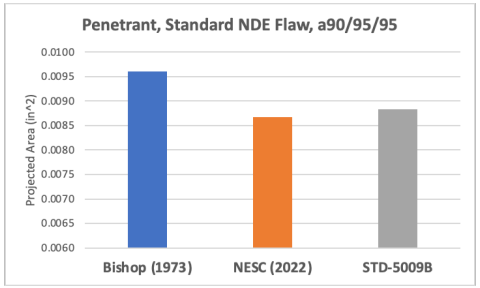
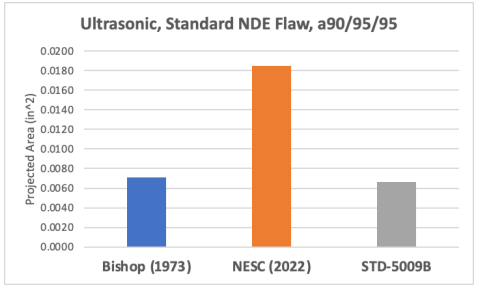
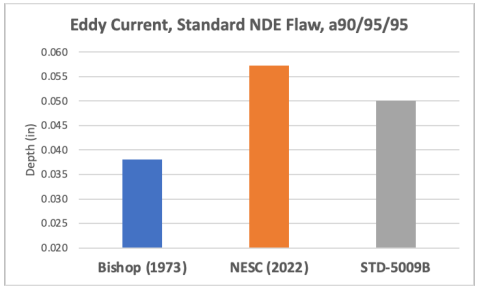
Radiography	[Flaw depth (d)] / [Specimen thickness (t)] x 100		
	Inspector	**Bishop (1973) [9]**	**Parker (2022) [3]**
		(d/t %)	(d/t %)
Individual Inspector a90/95 Flaw Sizes	A	53	59
	B	64	66
	C	66	67
	D	59	70
	E	65	79
	F	60	77
	G	58	74
Inspector Average a90/95		61	70
NASA Standard NDE a90/95/95 Flaw Size		**70**	**83**









Bishop's reported Area is shown for PT; however, the correct calculation is 0.004 in^2

Plot of 5009 Area is based on 2c/a = 2

Summary of Historical Data Review

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- No clear traceable link to all entries in 5009's Standard NDE table was found
  - Table entries are a combination of POD studies and expert judgement/experience
- 5009's Standard NDE flaw sizes are not consistently representative of 95% inspector coverage, and the deviation varies by technique and aspect ratio
- 5009's Standard NDE table has served its purpose well, and we recommend not updating the flaw sizes in the table, only clarifying their source and interpretation in 5009's revision

New Standard NDE Method Requirement

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- Standard NDE POD study shall consist of a MIL-HDBK-1823A compliant POD study of a minimum of 10 inspectors that form a representative sample of inspectors
- Individual inspector analyses shall be performed in accordance with MIL-HDBK-1823A and estimated a90/95 flaw sizes for the individual inspectors shall be reported
- Individual inspector POF shall be reported and are recommended to not exceed 1% POF with 50% confidence
- Standard NDE flaw size shall be estimated as a function of the average and standard deviation of individual inspector a90/95 flaw sizes, and it shall represent the flaw size that 90% of inspectors are expected to demonstrate at least 90/95 detection capability

Standard NDE Analysis Guidance

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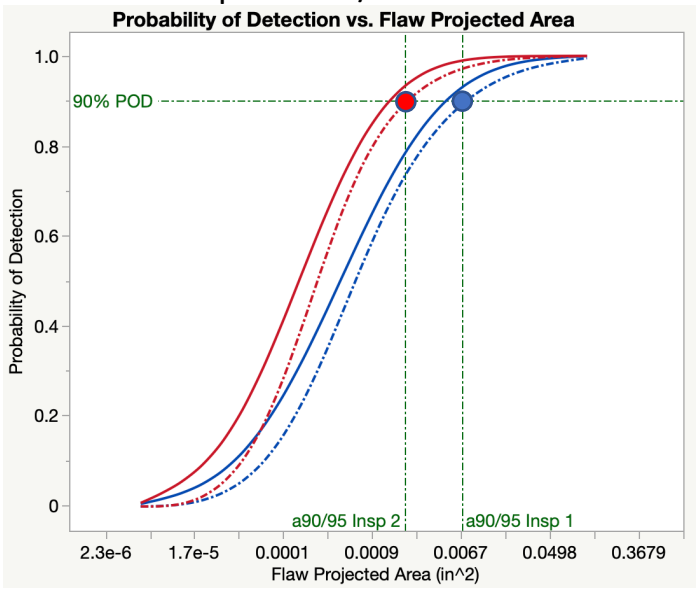
Individual Inspector Probability of False Call (POF) estimates from Unflawed specimens/sites

Individual Inspector POF ≤ 1% ?

Yes → Include in Standard NDE

No → Investigate Cause

Individual Inspector 90/95 Flaw Size estimates



Estimate Standard NDE Flaw Size

Standard NDE Flaw Size a90/95/90 = Average 90/95 Flaw Size across Inspectors + Uncertainty Factor for 90% Proportion Inspectors with 50% Confidence x Standard Deviation of 90/95 Flaw Sizes among Inspectors

Numerical Examples

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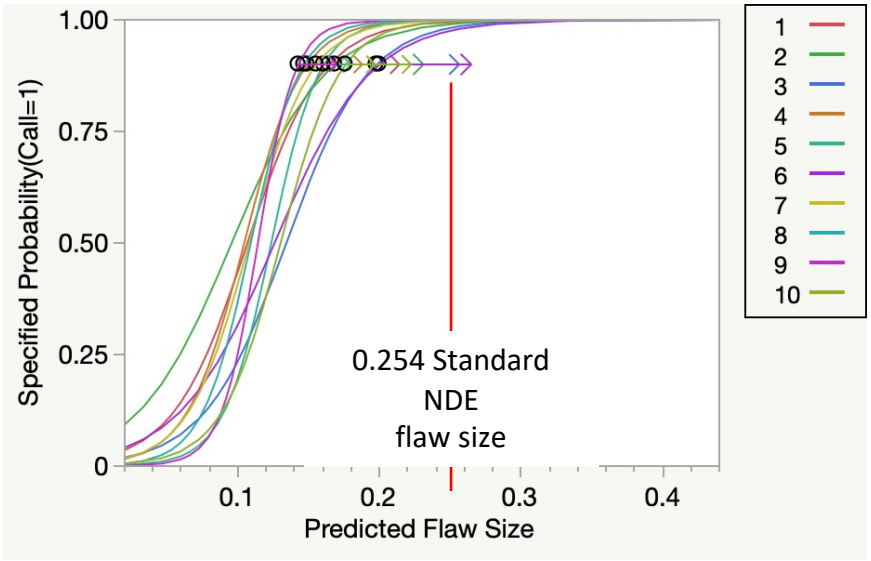
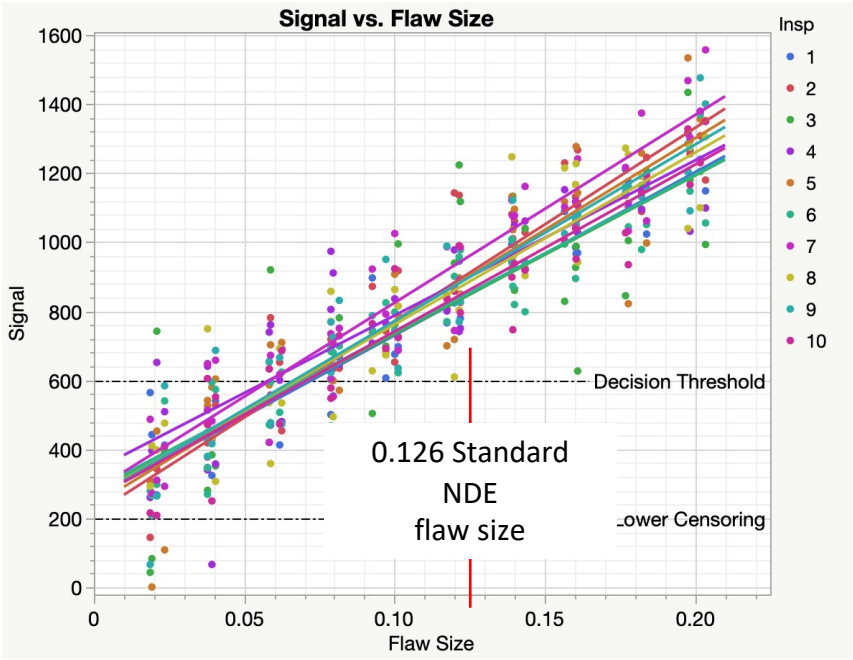
NDE hit/miss Method (e.g., penetrant)



Individual Inspector POD models
a90 (circle marker) and a90/95 (arrow tip) flaw sizes

NDE Signal-Response Method (e.g., eddy current)



Individual Inspector NDE signal versus flaw size models

Summary Comments

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- Historical review of original NASA Standard NDE POD study identified a number of issues and lessons learned
- Resulted in a new methodology to update existing Standard NDE flaw sizes and add new NDE methods
- Leverages lessons learned from Space Shuttle Program studies, NDE literature, and augments MIL-HDBK-1823A
- Unified approach of a POD study through design, execution, analysis, and documentation
- Intuitive to NDE practitioners and fracture analysts
- First documented NASA Standard NDE approach
- Addresses a long-standing gap in the Standard NDE body of knowledge, and it undergirds the continued usage of Standard NDE flaw sizes for NASA systems